

Sec 14

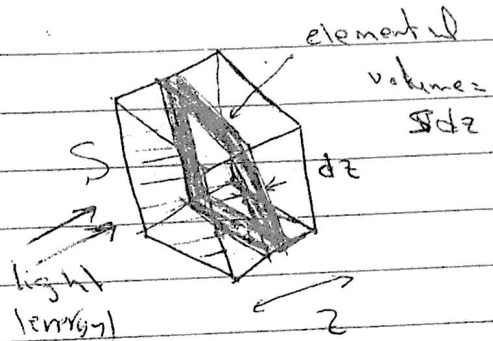
Date:

15/11/21

stimulated Emission Amplification

cross sectional area

propagation direction



by
 $\text{Power} = \frac{\text{energy}}{\text{unit time}}$

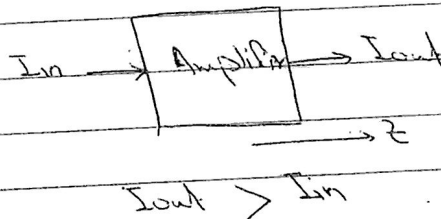
radiance = $\frac{\text{Power}}{\text{unit area}} = I$

energy density = $\frac{\text{energy}}{\text{unit volume}}$

② Stimulated Emission

① Absorption

design amplifier?



no of absorption (E_{abs})

$$R_{ap} = B \times P_v \times P_{abs} \times U$$

where: $B = \frac{U^3}{8\pi h^2 \nu^3}$, $U =$ speed of wave inside material
 $\nu =$ frequency of incident wave

R_{ap} : no of absorbed photons/unit volume/unit time

$$\text{no. of absorbed photons in volume } (Sdz) = B P_v \times P_{abs} \times U \times Sdz$$

$$\text{energy absorbed in } Sdz = B P_v P_{abs} U Sdz \times h\nu$$

Similarity:-

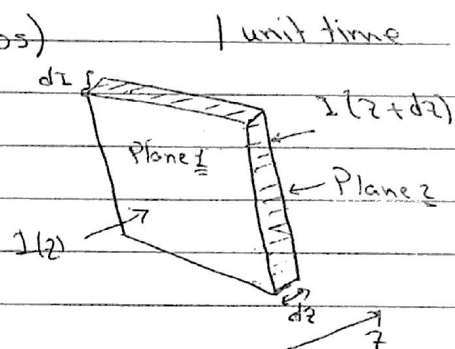
$$\text{Energy emitted} = J_{st} \times S dz \times h \nu$$

$$= B P_e P_e U S dz h \nu$$

$$\text{Net energy} = \text{emitted} - \text{Absorption}$$

$$= B P_e U S dz h \nu (P_e - P_{abs})$$

$$dI \times S \Rightarrow \text{power}$$



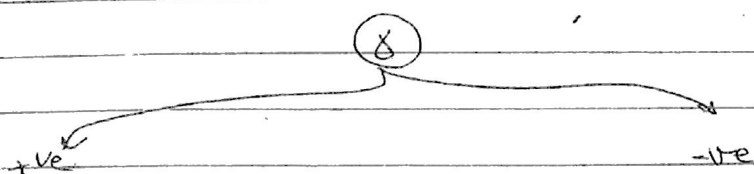
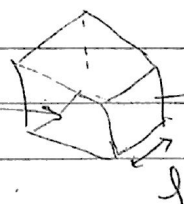
$$dI \times S = B P_e U S dz h \nu (P_e - P_{abs})$$

$$\frac{dI}{dz} = B P_e U h \nu (P_e - P_{abs})$$

$$U = \frac{I}{c}$$

$$\frac{dI}{dz} = \frac{B P_e h \nu (P_e - P_{abs})}{U_{photon}} I(z)$$

$$\frac{dI}{dz} = \gamma I(z) \quad \therefore I(z) = I_0 e^{\gamma z}$$



$$I_{out} > I_{in}$$

Amplifier

$$G_{gain} > 1$$

$$P_e > P_{abs}$$

$$I_{out} < I_{in}$$

Attenuator

$$G_{loss} < 1$$

$$P_e < P_{abs}$$

Date

$$\gamma = \frac{B P_v h \gamma (P_e - P_{abs})}{v}$$

$$P_v = \frac{1}{\pi h^2} (2m v)^{3/2} (h \gamma - E_g)^{1/2}, \quad h \gamma > E_g$$

$$B = \frac{v^3}{8 \pi h \gamma^3}$$

two Fermi levels E_c, E_v → $P_e > P_{abs}$ → amplifier

two Fermi functions.

$$P_e = f_c(E_2) \times [1 - f_v(E_1)] = \frac{1}{e^{(E_1 - E_c)/kT} + 1} \cdot \frac{e^{(E_1 - E_v)/kT}}{e^{(E_1 - E_v)/kT} + 1}$$

$$P_{abs} = f_v(E_1) \times [1 - f_c(E_2)] = \frac{1}{e^{(E_1 - E_v)/kT} + 1} \cdot \frac{e^{(E_2 - E_c)/kT}}{e^{(E_2 - E_c)/kT} + 1}$$

$$P_e > P_{abs}$$

$$e^{(E_1 - E_v)/kT} > e^{(E_2 - E_c)/kT}$$

$$E_1 - E_v > E_2 - E_c$$

$$E_c - E_v > E_2 - E_1$$

$$E_2 - E_1 < E_c - E_v$$

$$h \gamma < (E_c - E_v)$$

$$E_g < h \gamma < E_c - E_v$$

$$\frac{E_g}{h} < 1 < \frac{E_c - E_v}{h} \Rightarrow \text{Amplification}$$

$$P_e - P_{abs} = f_c(E_2) \times [1 - f_v(E_1)] - f_v(E_2) \times [1 - f_c(E_1)]$$

$$= f_c(E_2) - f_v(E_1)$$

$$\delta = \frac{v^3}{8\pi h^2 v^2} \times \frac{1}{\pi h^2} (2m)^{3/2} \frac{h^2}{v} (h\nu - E_g)^{1/2} [f_c(E_2) - f_v(E_1)]$$

$$\delta = \frac{v^2 (2m)^{3/2}}{2h^2 v^2} (h\nu - E_g)^{1/2} [f_c(E_2) - f_v(E_1)]$$

ex: at $T = 0^\circ K$

(a) at Thermal equilibrium:

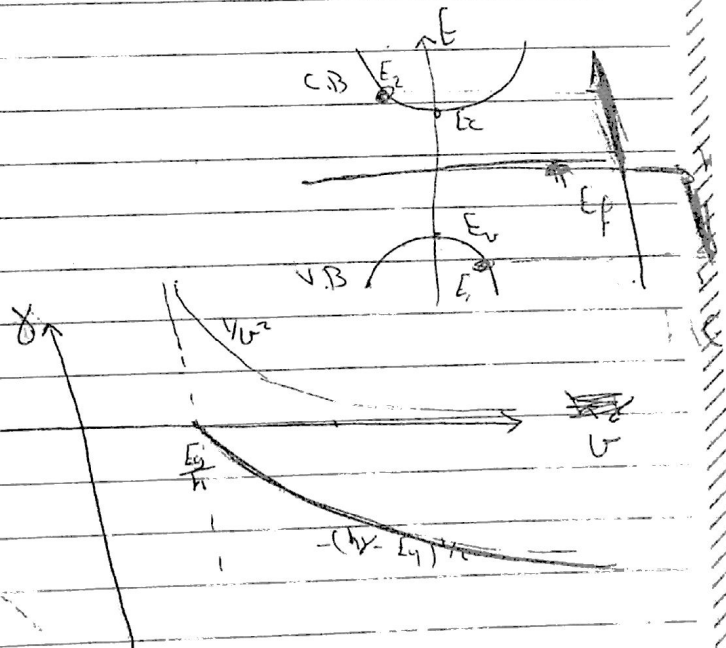
$$f(E_2) = 0$$

$$f(E_1) = 1$$

$$f(E_2) - f(E_1) = -1$$

$$\delta = -ve$$

attenuator



(b) at Quasi Equilibrium:-

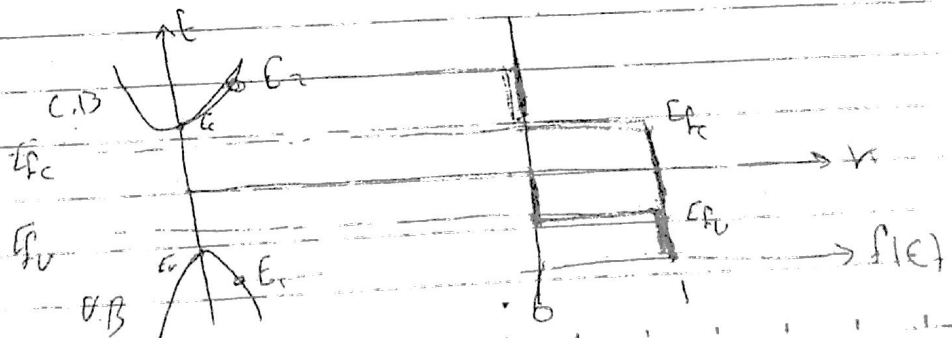
$$f(E_2) = 0$$

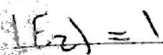
$$f(E_1) = 1$$

$$f(E_2) - f(E_1) = -1$$

$$\delta = -ve$$

attenuator



$$(E_{fc} - E_{fu}) > E_g$$


$$P(E_1) = 0$$

$$f_E(E_2) - f_E(E_1) = 1$$

$$\delta = \mu e$$

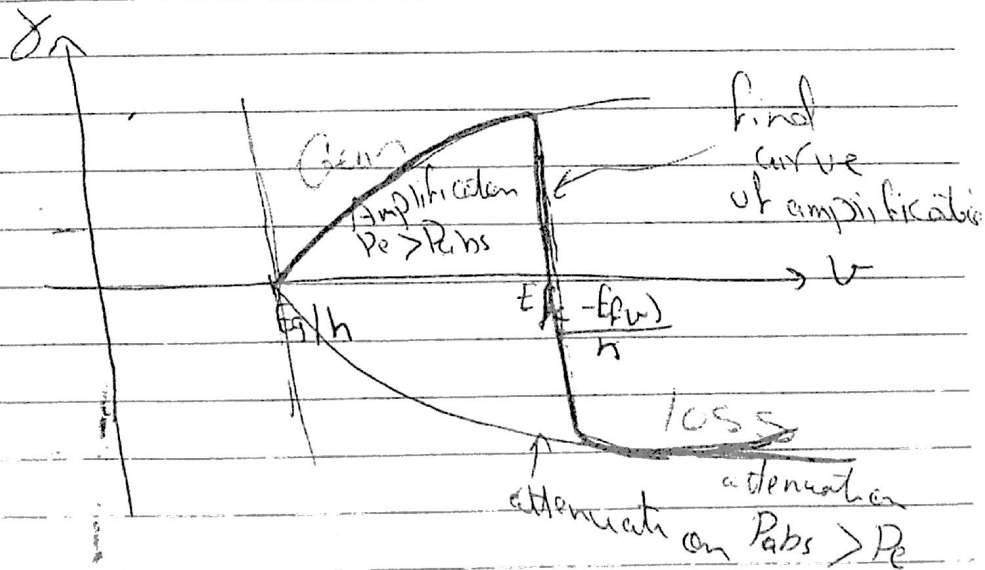
Amplifier

emission zero or 1 and the photon ~~is~~ ϵ and x

إذا كان فرق الطاقة أقل من $E_F - E_{F_0}$

absorption \rightarrow $\frac{I_0 - I_t}{I_0}$ extinction coefficient \rightarrow photon level *

إذا كان $f_c - f_v$ أكبر



ex:- $E_g = 1 \text{ eV}$

$E_{fc} - E_{fv} \approx 12 \text{ eV}$

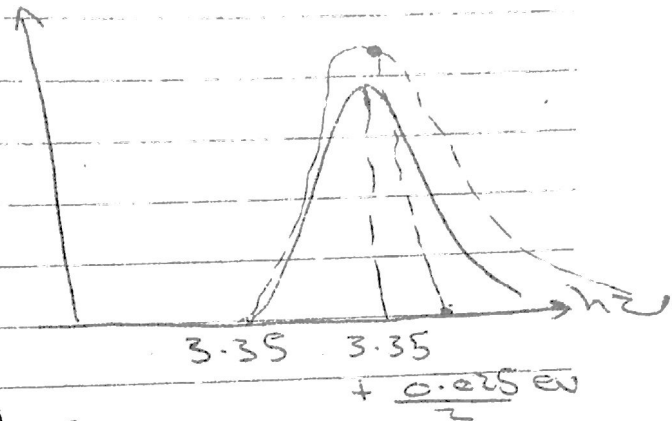
$$\frac{E_g}{h} = \frac{1 \times 1.6 \times 10^{-19}}{6.6 \times 10^{-34}} \approx 0.25 \times 10^{15} \text{ Hz} = \underline{\underline{250 \text{ THz}}}$$

$$\frac{E_{fc} - E_{fv}}{h} = \frac{1.2 \times 1.6 \times 10^{-19}}{6.6 \times 10^{-34}} =$$

$$BW \approx \frac{0.2 \times 1.6 \times 10^{-19}}{6.6 \times 10^{-34}} \quad \# \quad \ll$$

GaN $E_g = 3.35 \text{ eV}$

GaN $E_g = 3.35 \text{ eV}$



موضوع: جز 18 - فاعل المادة

Semicond Direct mat

Bumping Forward Bias

X
أفصح
مراجعة
الدرس

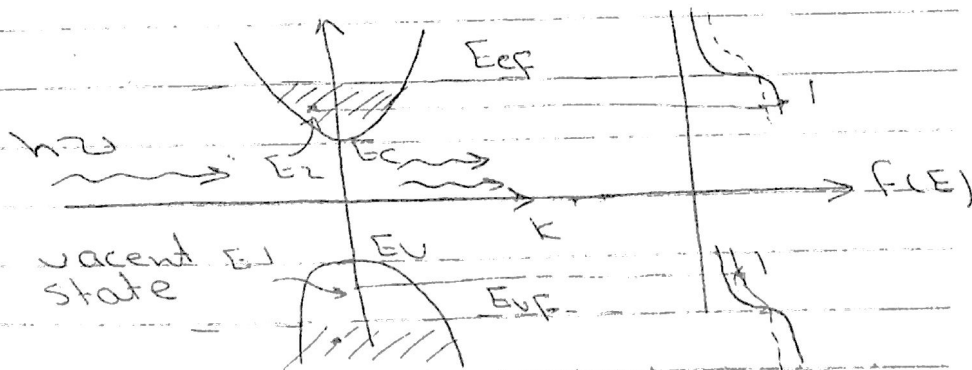
lec (15)

دنیال

$$\gamma = \frac{(c/n)^2 (2m_r)^{3/2} (h\nu - E_g)^{1/2}}{2\tau_r (h\nu)^2}$$

$$X(\int_c(E_2) - F_Y(E_1))$$

at $T = 0\text{ K}$ $f_c(E_2) - f_v(E_1) = 1$



15

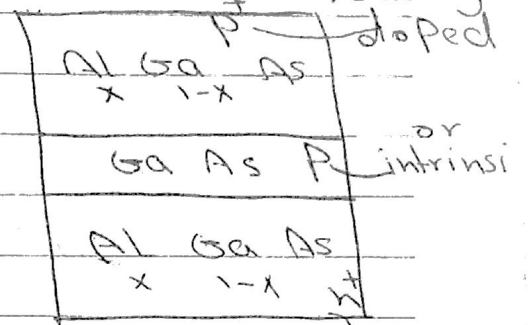
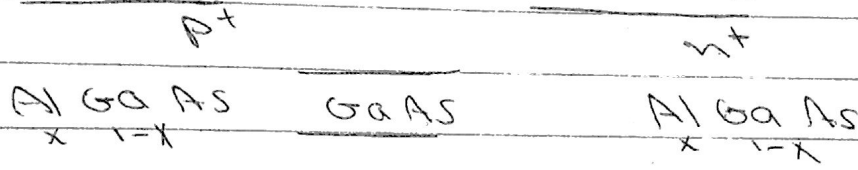
Man structure

double heterostructure

Band diagram

majority carriers = holes

heavily doped



heavily doped

assume

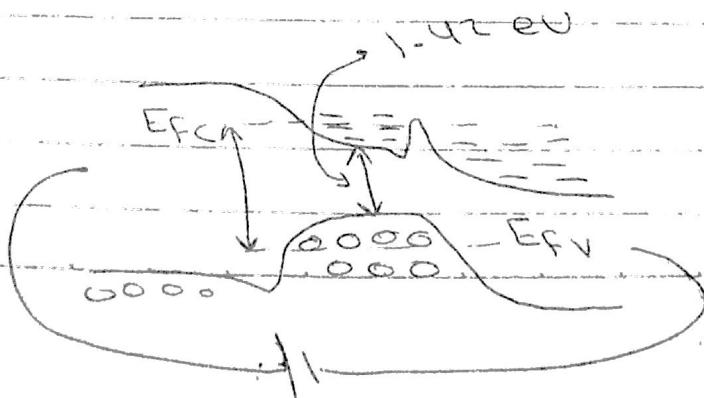
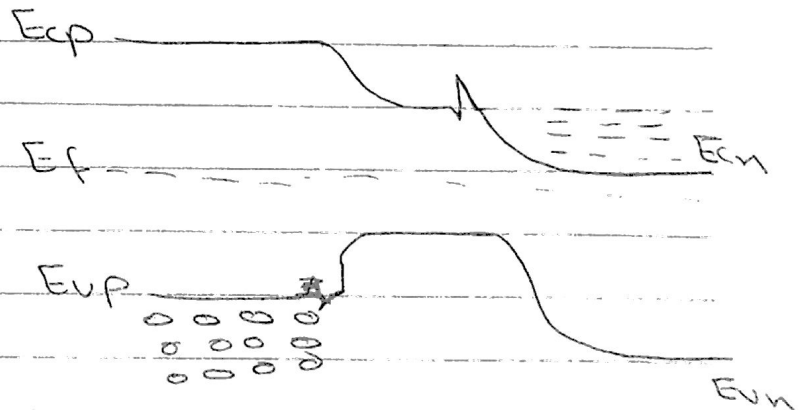
$$x = 0.1$$

$$E_g = 1.5 \text{ eV}$$

$$E_g = 1.42 \text{ eV}$$

minority carriers electrons

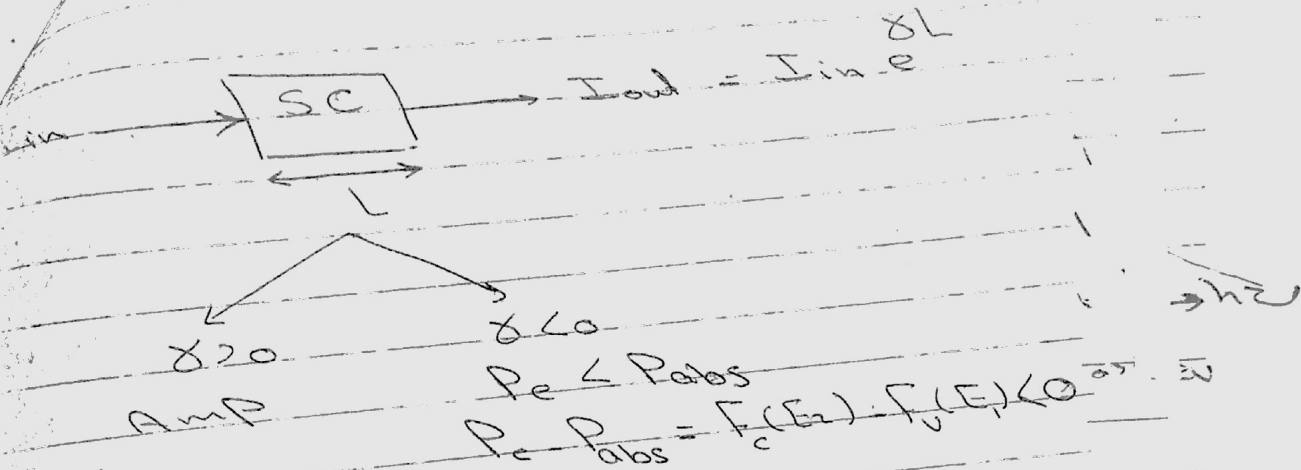
steady state



في حالة التوازن
F.B

[3]

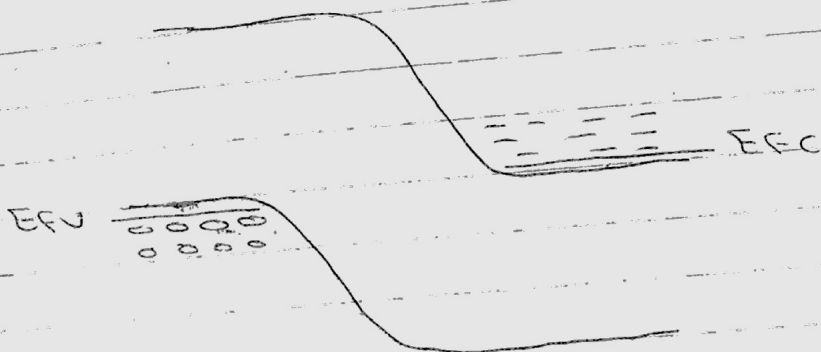
Attenuation



n junction



input \downarrow 0000 \uparrow --- FB class
RB class output



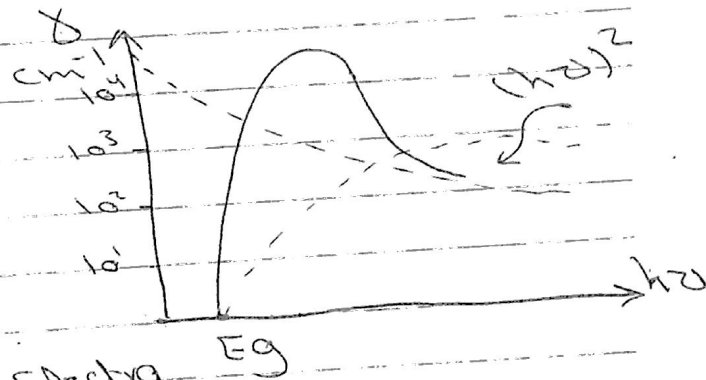
Absorp Spectrum

$$\delta = -\alpha_{\text{abs}}$$

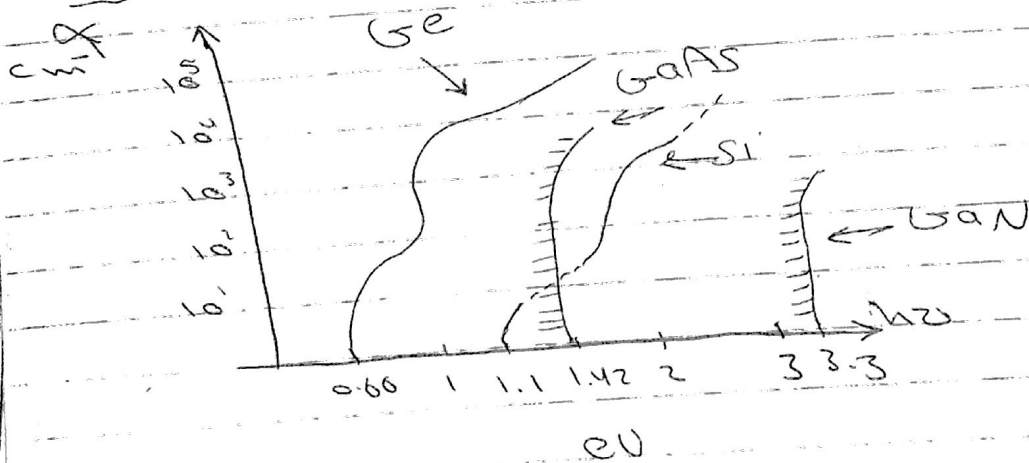
directly proportional

to $(h\nu - E_g)^{1/2}$

$$\alpha_{\text{abs}} = \frac{(c/n)^2 (2\pi\nu)^{3/2}}{2Z_r (h\nu)^{1/2}} (h\nu - E_g)^{1/2}$$



Typical Absorption Spectra



Comments on curve

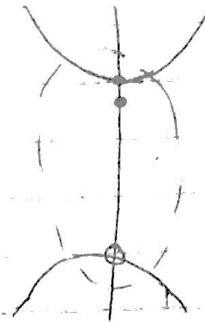
* Any material either Direct or Indirect absorp

* Absorption increases with Freq

→ curves consider indirect band gap

E_g - Binding energy
(10 meV)

All Energy 11 slices
expanded



attraction
Coulomb's force

Excited electron hole
pair

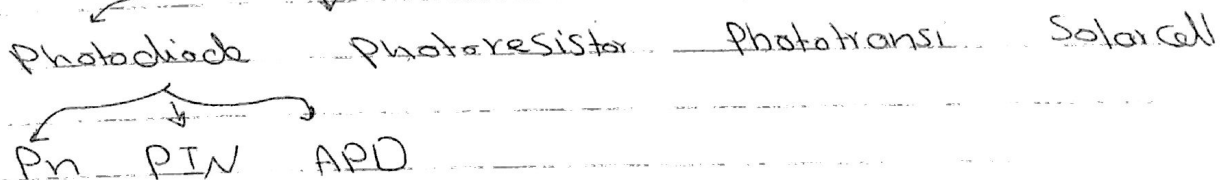
report about (4) Nano Structure mat

lec (16)

النظري

Photo conductors

Device that its conductivity changes
with the light incidence



General ck's

1. Quantum efficiency η
2. Responsivity R
3. Response time
4. Noise Power

created carrier flux $\frac{I_{ph}}{e}$

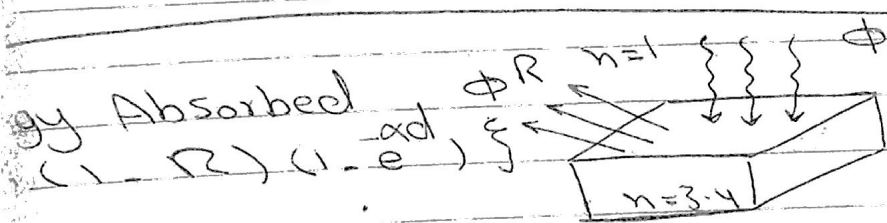
incident Photon flux $\frac{P_{opt}}{h\nu}$

Power

$$\frac{I_{ph}}{P_{opt}} \left(\frac{h\nu}{e} \right) \rightarrow \left(\frac{h}{e} \right) \left(\frac{c}{\lambda} \right) = \frac{1.24}{\lambda (\mu m)}$$

$\downarrow R (A)$

$$R = \frac{1.24}{\lambda (\mu m)} \quad R = \frac{1.24}{\lambda (\mu m)}$$



$$I_{in} \rightarrow (1 - e^{-\alpha d}) \rightarrow I_{in} e^{-\alpha d}$$

absorption coefficient material

$$\eta = (1 - R) (1 - e^{-\alpha d}) \quad \eta \geq 0$$

how to maximize η ?

R (reflection) \ll

coating In_2O_3

Indium tin oxide In_2O_3

thickness of coating material function of incident wavelength

(2)

Designed PD is tuned at specific wavelength

② $\alpha d \ll 1$

$\alpha d \gg 1$

(thickness of PD) $\uparrow \uparrow$

$\propto \uparrow \uparrow$ (atten const)

المادة $\propto \ll$ $\alpha d \gg 1$ $\propto \uparrow \uparrow$ (atten const)

③ \downarrow material ~~functions~~ fabrication

\leftarrow less dangling bonds \leftarrow less defects

less trap states \rightarrow high performance

② R
المادة $\propto \ll$
جاء بورتالي

①

R

Si

InGaAs

Short wavelength

Long wavelength

0.3 0.8 1.4 1.6 1.7 (um)

1100 nm position

~ 1.25

min $E_g \equiv$ MAX λ

thermization

المادة $\propto \ll$

R curve, abs curve

③

InGaAs	μ_e 14000	μ_h 400
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∴ $\mu_e > \mu_h$ ∴ n layer is important

To min time response

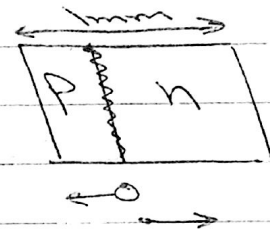
- ① dimension of n & p layers in PD should be adjusted as shown in below to achieve compromise speed for i.e., i_p

- ② Choose material with high mobility

ex):

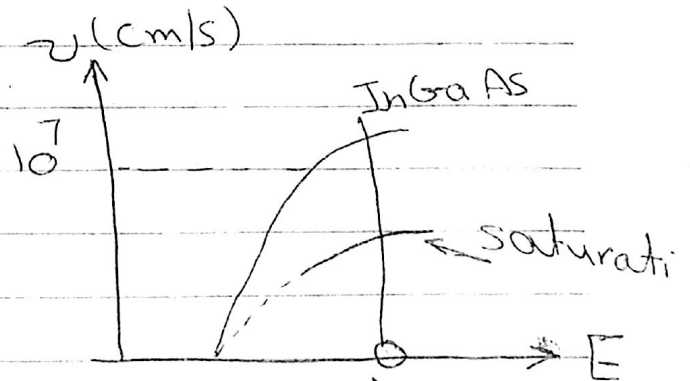
$$t_{s,} = \frac{1\text{mm}}{\mu_e} \quad \mu_e = 10^7 \text{ cm/s}$$

$$t_s \approx 10^{-8} \text{ s} \quad \mu \uparrow \quad t_s \downarrow$$



- ③ Apply E to help electrons & holes to move fast

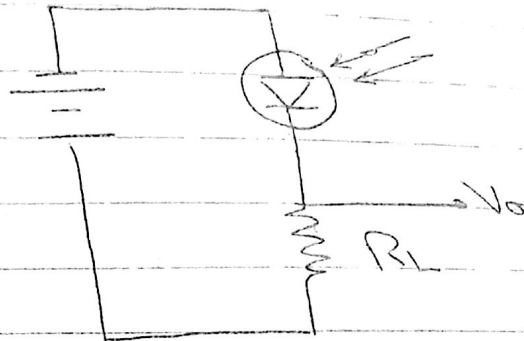
E is electric field
saturation μ



- ② Recombination time in circuit

response \uparrow recomb $t \downarrow$ $R_L, C \downarrow$

(5)

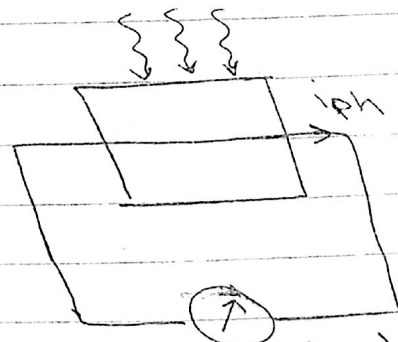


Give reason to use InGaAs - it)

- ① R. curve
- ② High speed \rightarrow low time response

Noise power

dark current generated
reverse circuit without
incident light

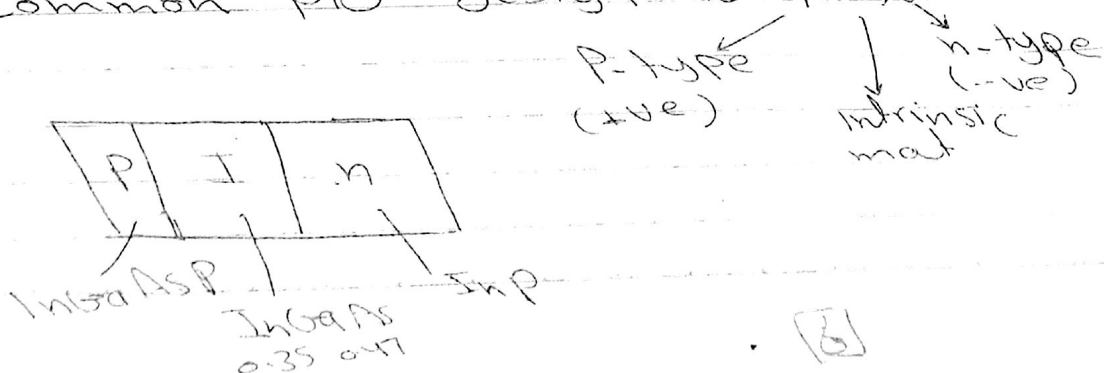


dark current generated

Si	~ 1 nA	ضوء
InGaAs	~ 10 nA	Sensing
Ge	~ 100 nA	ضوء

noise power

Common p-i-n Design is PIN



[6]